

Mapping Submerged Aquatic Vegetation in the Great Lakes Using Satellite Imagery

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The *Cladophora* Problem

- *Cladophora* is a native, filamentous, green alga that grows attached to solid substrate in all of the Laurentian Great Lakes (sparse in Lake Superior).
- Becomes detached after significant storm events and washes up along shore, impairing recreational use of the lakes, clogging water intakes and facilitating avian botulism outbreaks.
- Nuisance growth has become an increasing problem over the past decade despite reduced phosphorus loadings, due mostly to the arrival of invasive mussel species.
- Mussel filtering is increasing water clarity, allowing *Cladophora* & other SAV to grow in deeper water.
- Mussel “colonies” also create new areas of hard substrate where *Cladophora* can grow.

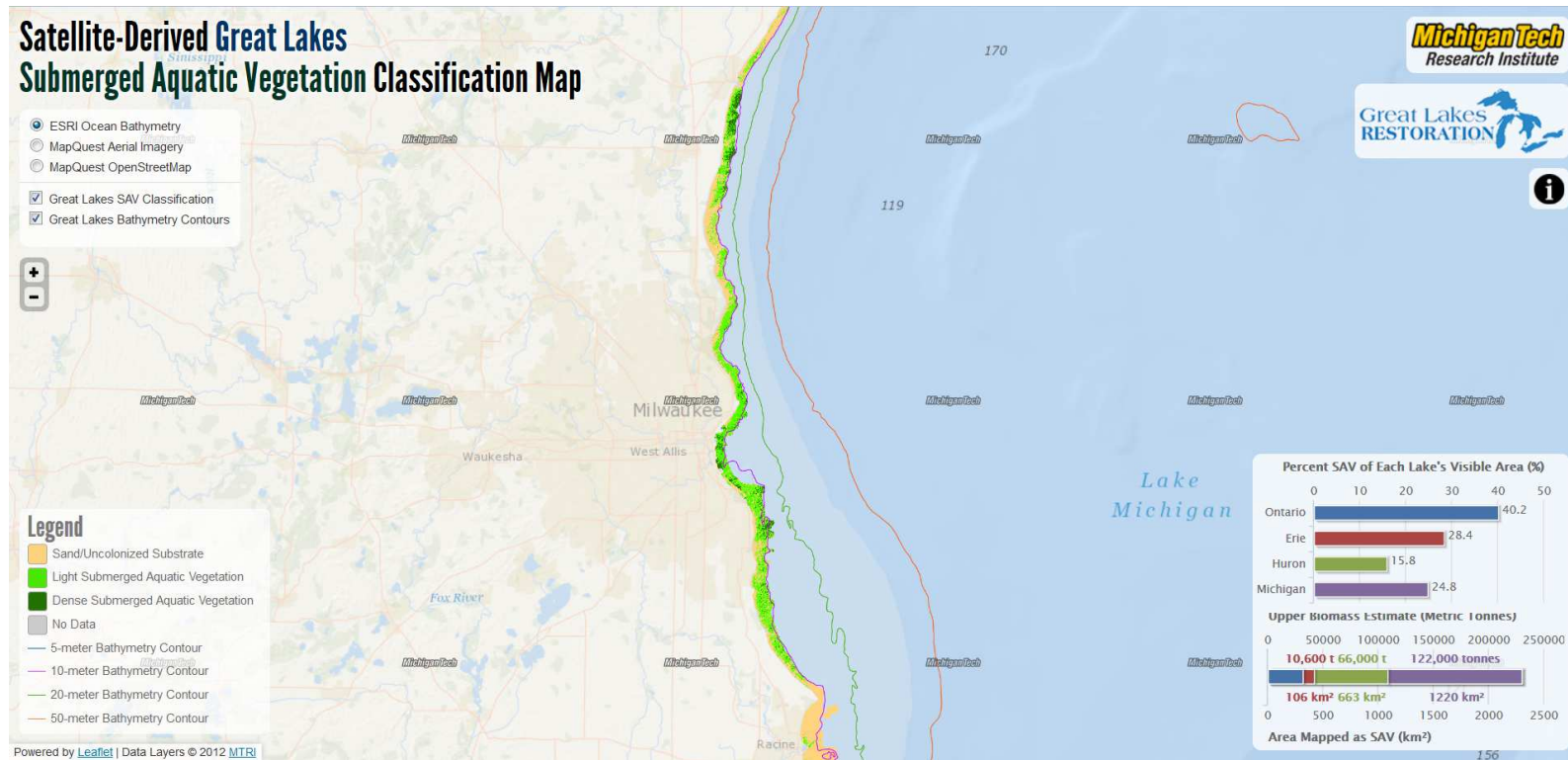


Mapping and Monitoring the Extent of Submerged Aquatic Vegetation in the Great Lakes

- MTRI used Landsat satellite imagery to map the **ca. 2010 extent of submerged aquatic vegetation** in Lakes Michigan, Huron, Erie and Ontario.
- Starting with raw Landsat imagery, a **depth correction algorithm** is used to eliminate radiance due to the water column, leaving just the radiance reflected from the lake bottom
- By plotting multiple depth-corrected spectral bands (typically blue and green visible light) against one another, **we can discriminate between bottom types** (sand, mud, sparse and dense SAV)



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- Web-based, interactive GIS-style map established for all lake-wide SAV maps:

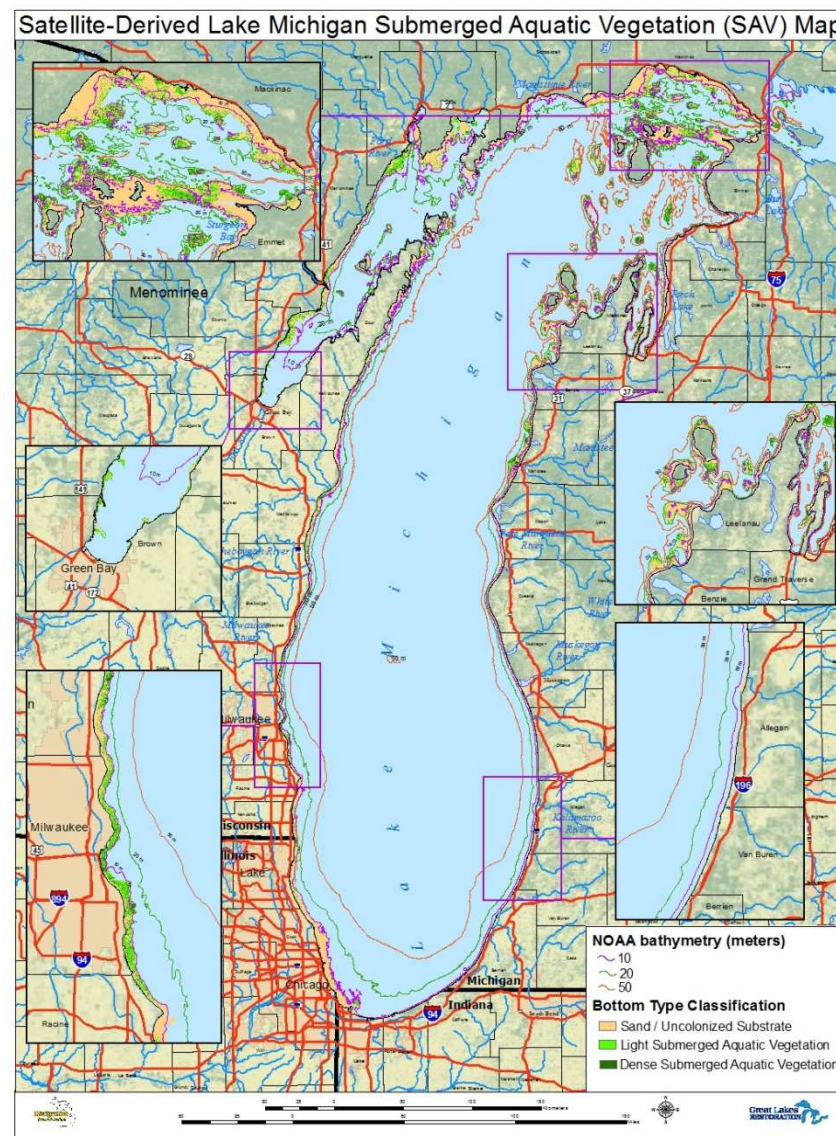
<http://geodjango.mtri.org/static/sav/>

(via <http://www.mtri.org/cladophora.html>)

Lake Michigan SAV/Cladophora Map

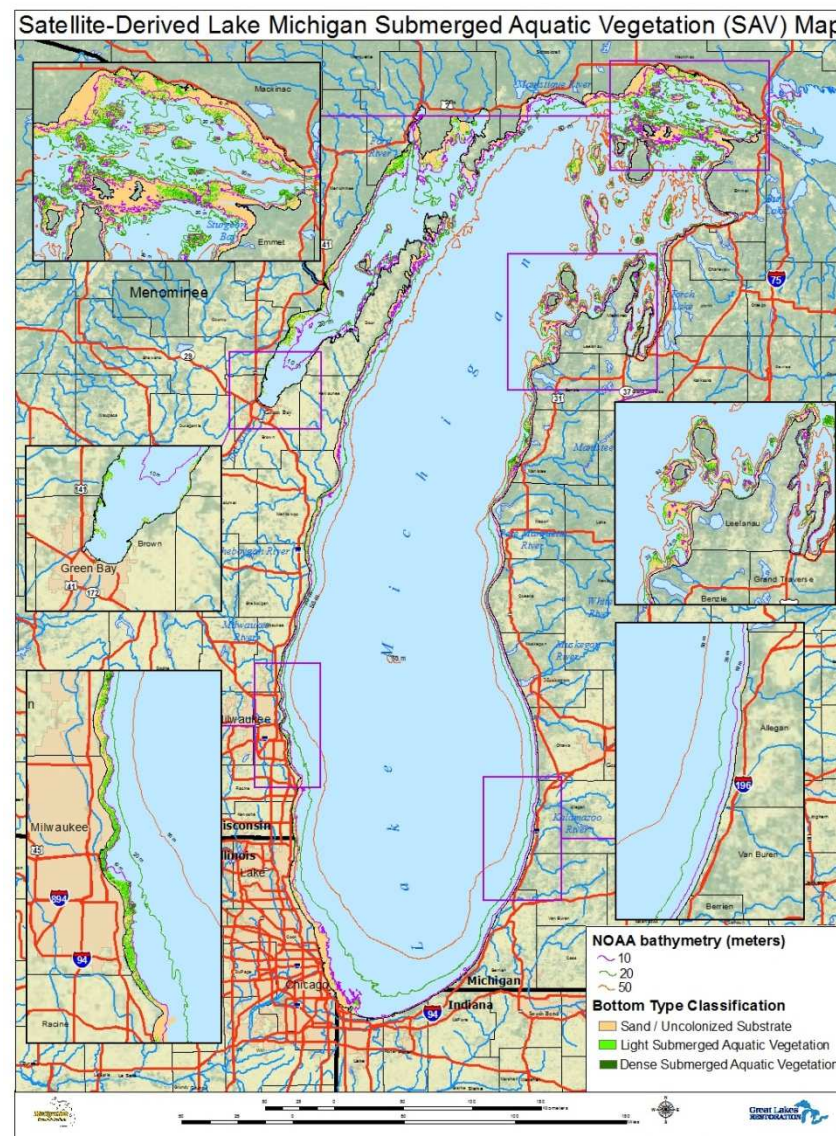
- In Lake Michigan 28% of the visible bottom consisted of Submerged Aquatic Vegetation (SAV) (1220 km² out of the 4390 km² of visible bottom mapped)
- MTRI's nominal estimate of the dry weight biomass of the SAV in Lake Michigan is 67,000 metric tonnes.
- 30 m resolution map

Available at <http://www.mtri.org/cladophora.html>



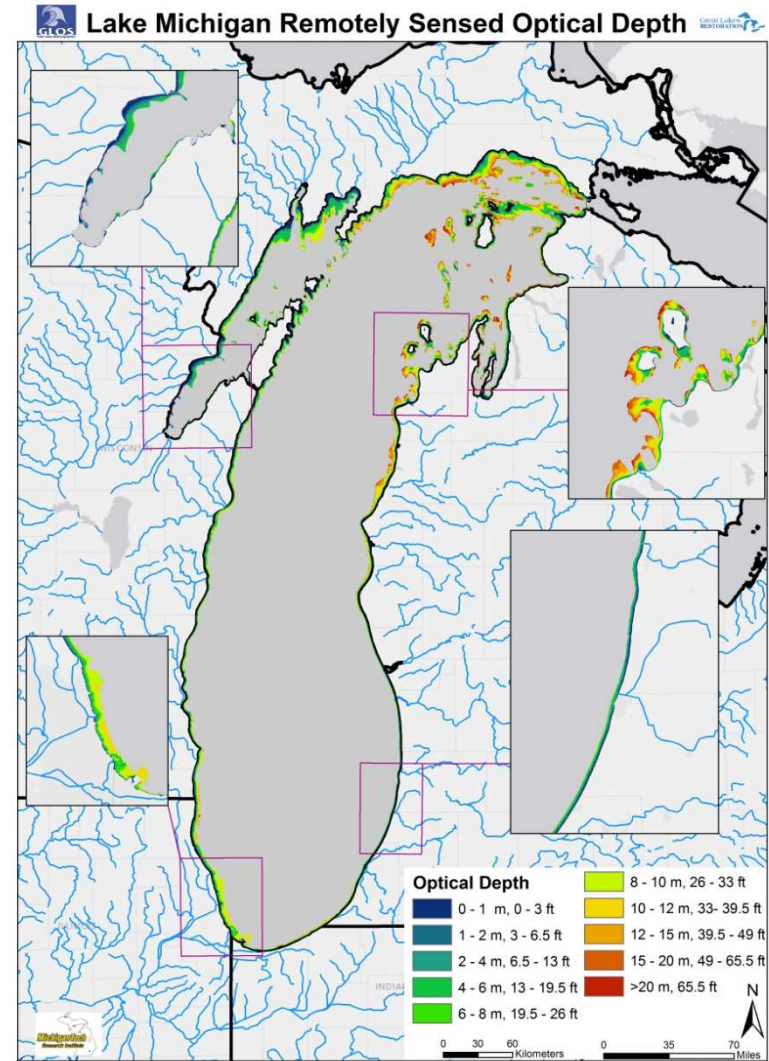
Lake Michigan SAV/Cladophora Map

- Four main areas of concentrated SAV growth
 - Sleeping Bear Dunes
 - Green Bay
 - North end
 - Milwaukee
- Apart from Milwaukee, these bloom areas are likely driven by nonpoint runoff rather than urban pollution
- Mean satellite optical depth of 12 m (max >20 m)



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- MTRI's bottom mapping procedure can also be used as an additional measure of water clarity
- Northern Lake Michigan shows the greatest optical depth while southeast Lake Michigan shows the least.
- Optical depth varies from 2 to 20+ meters
- Optical depth can be used to estimate water clarity, photosynthetically active radiation, and photic zone



SAV Statistics by Lake

Lake	Total Lake Bottom Area Mapped by Satellite (km ²)	Area Mapped as SAV (km ²)	Percent SAV of total area visible	Approx. SAV Dry Mass (metric tons)
Lake Michigan	4390	1220	28%	67,000
Lake Huron	4370	665	15%	36,000
Lake Erie	530	160	30%	9,000
Lake Ontario	790	315	40%	17,000

- Total area mapped represents the geographic extent of optically shallow water that could be mapped with the Landsat sensor
- Dry weight biomass estimates are derived from the mapped area of SAV and a nominal dry density of 50 g/m² SAV
- Estimates multiplied by 1.1 to account for SAV growing in optically deep water (based on the Great Lakes *Cladophora* Growth Model)
- Basin-wide total of approximately **129,000** metric tonnes dry weight

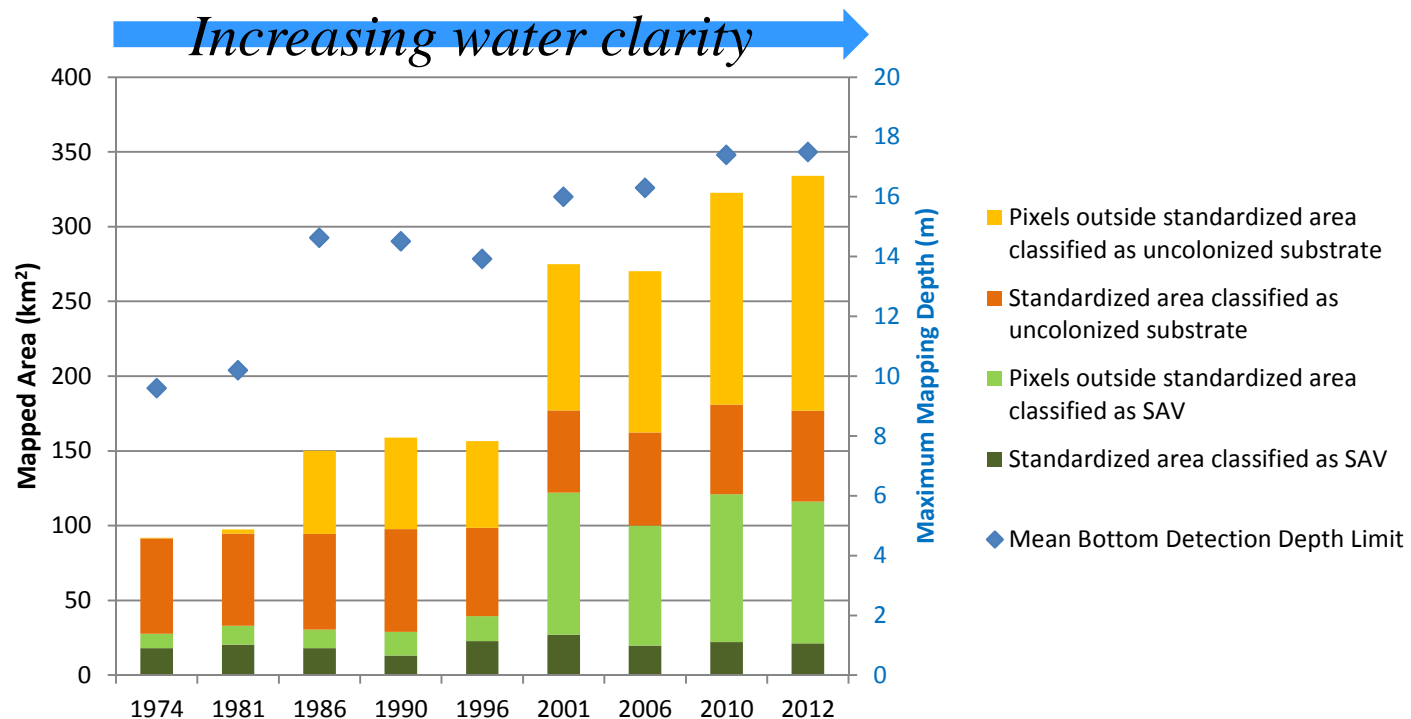
SAV Time Series Maps

- Historic Landsat imagery was used to map SAV at 5 sites at approximately 5-year intervals from the mid-1970s to the present
- These map series were then used to track total mappable area, the area mapped as SAV, and the maximum mapping depth over time.



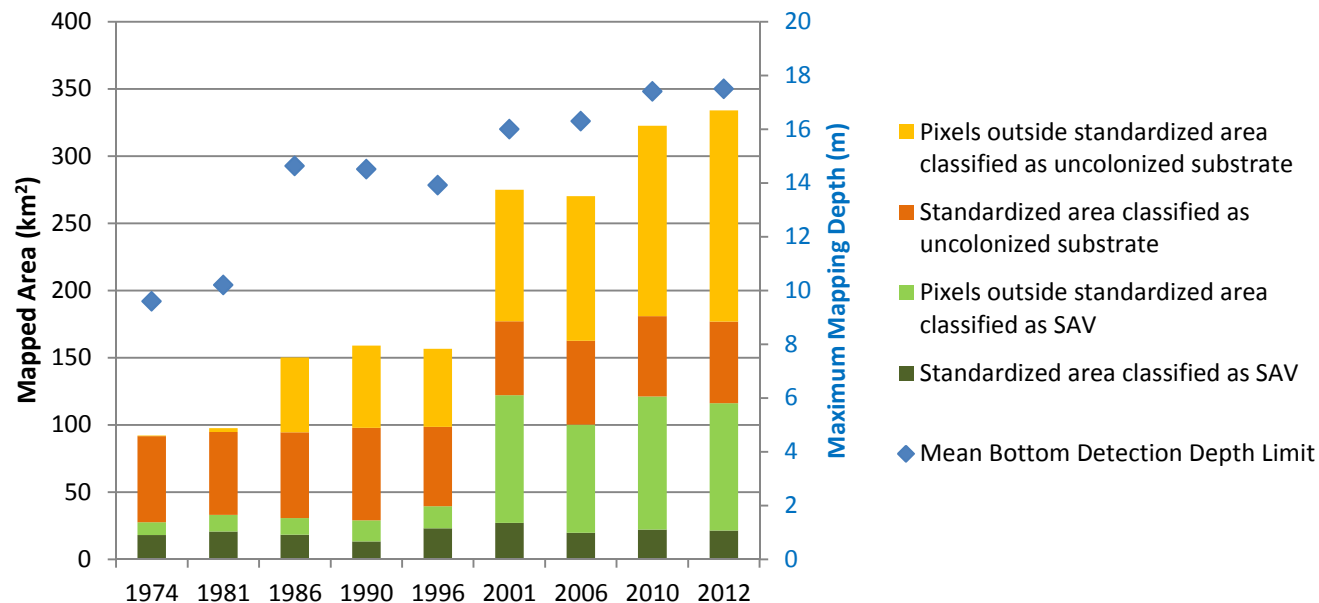
Sleeping Bear Dunes National Lakeshore—Lake Michigan

- Darker bar colors (■, ■) indicate the pixels that could be classified in every year of the time series (standard area over time)
- Lighter colors (■, ■) were only classifiable in some years
- Blue diamonds = maximum mapping depth based on water clarity



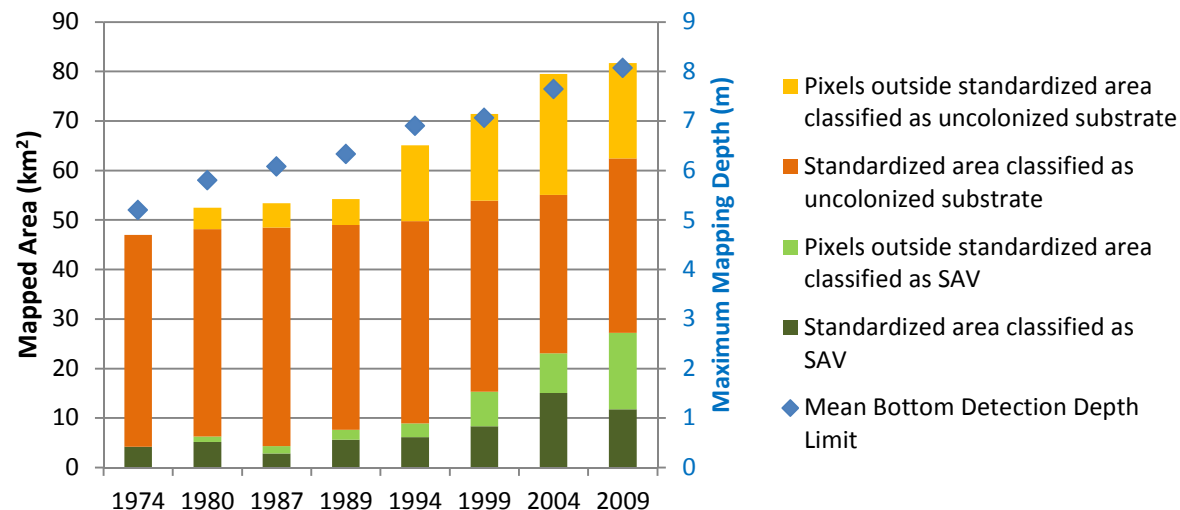
Sleeping Bear Dunes National Lakeshore—Lake Michigan

- Total area mapped as SAV at Sleeping Bear has increased nearly four-fold
- Total mapped area increased more than three-fold due to higher water clarity

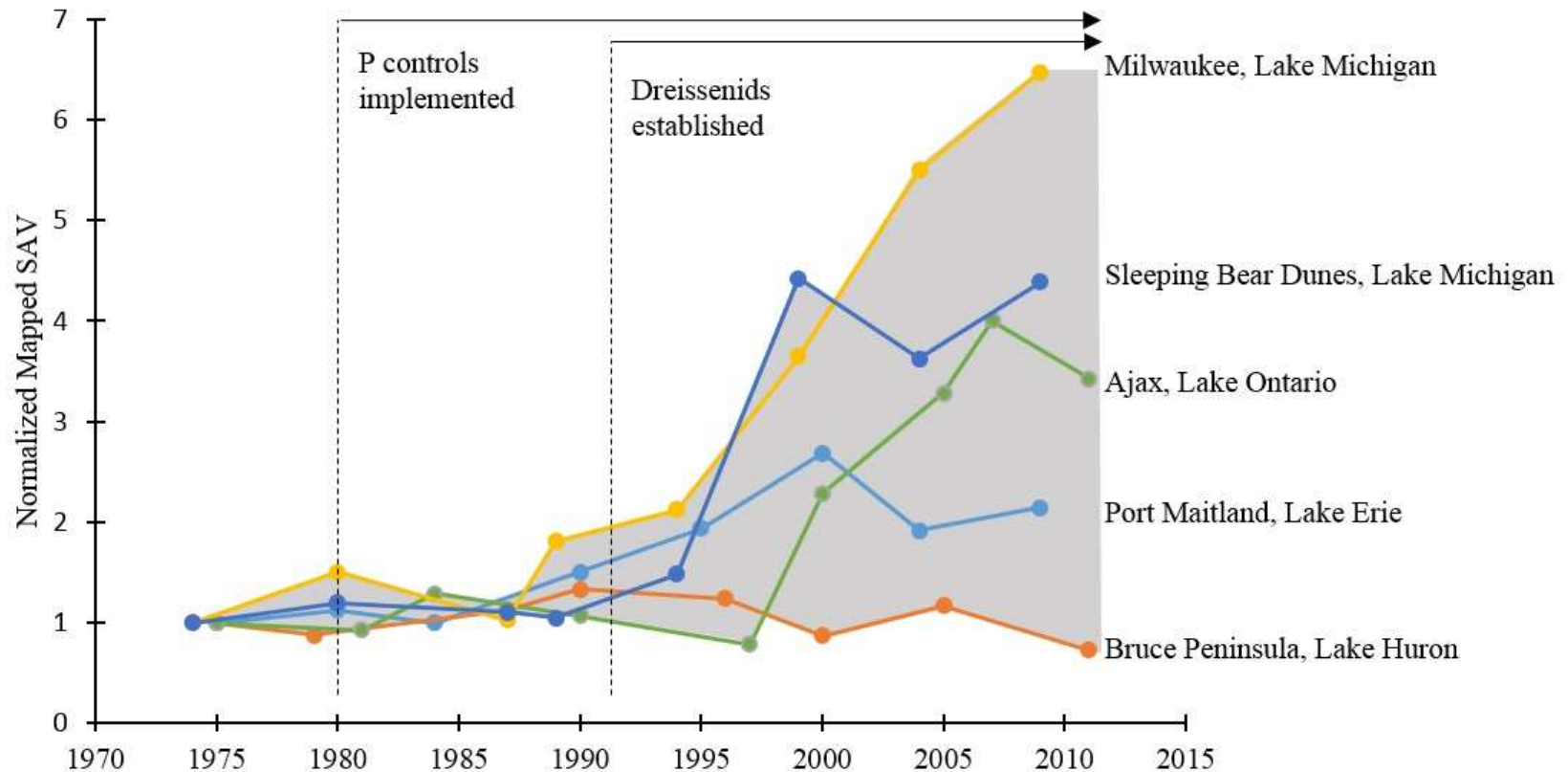


Milwaukee, WI—Lake Michigan

- Steady increases in both total area mapped and area mapped as SAV after 1994
 - Dreissenid mussels reached Lake Michigan approx. 1989
- Increases in SAV cover both inside and outside of the standardized lake bottom area



Overall patterns



Timeline of change in (normalized) SAV area at the five focus areas, annotated with relevant events

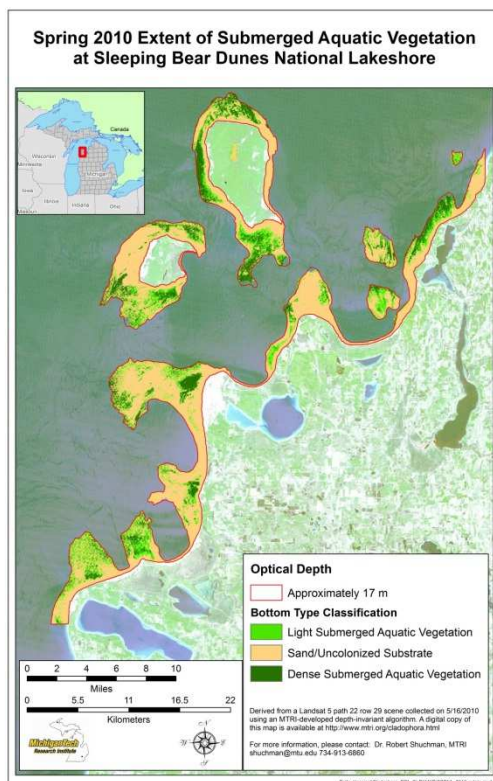
Overall patterns

- **Water clarity has increased significantly** in all four lakes as a result of the activities of invasive dreissenid mussels
- This increase in clarity is extending the area of suitable habitat for Cladophora and related vegetation into deeper water, leading to **increases in total SAV area**
- Multiple sites exhibit a **decline** in SAV cover in the 1980s that coincides with phosphorus control efforts, **then a resurgence** following the date of appearance of dreissenid mussels at that particular site

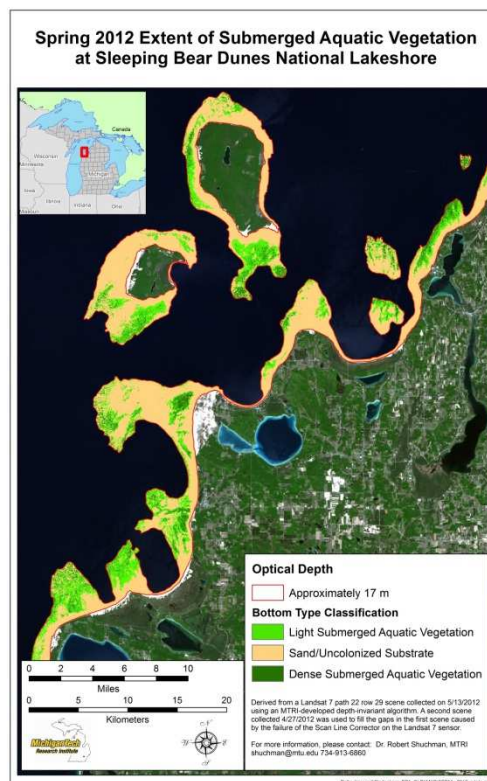
Overall patterns

- Many areas of especially concentrated SAV growth are clearly impacted by urban discharge (e.g. shorelines near Milwaukee, Toronto, Green Bay)
- Others are not, for example, Sleeping Bear Dunes. Multiple possible nonexclusive explanations for these 'hotspots':
 - Current flow carrying nutrients to the site from more distant inputs
 - Capture and recycling of allochthonous P by dreissenids
 - Increasing availability of hard substrate provided directly by mussel beds forming on softer substrates

Recent Updates: Sleeping Bear



2010:
34% classified as SAV
Max mapping depth 17.4 m



2012:
33% classified as SAV
Max mapping depth 18.2 m



2013:
37% classified as SAV
Max mapping depth 20.1 m

Recent Updates: Western Shoreline



All of our time series work indicates significant changes at a ~5 year interval—time for a basin-wide update!

SAV/*Cladophora* GLRI Study: Concluding Remarks

- Historic and current SAV cover varies along Great Lakes shorelines with ambient phosphorus levels, local nutrient sources, mussel density, water clarity, bottom substrate, and topography
- The MTRI SAV algorithm provides robust estimates of SAV cover with an overall accuracy of ~83%
- These basin-scale maps can help identify the priority watersheds for actions to reduce phosphorus loadings into the Great Lakes
- The baseline map is now 5 years old – an update is needed to reflect recent changes and take advantage of the new Landsat 8 sensor



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Questions?

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